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Formation Design Systems' Maxsurf Stability Tank Table Generator: Verification and Validation Study

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ABSTRACT

A verification and validation analysis was undertaken to prove that the Maxsurf Stability software can be used to generate platform tank calibration data in a format and standard that meets, or exceeds, the requirements imposed by the Maritime Institute of the Netherlands (MARIN) and the Cooperative Research Navies (CRNAV) ship stability working group. The results of the analyses show that the Maxsurf Stability software program (Version 20.00.00.59) generates tank calibration data and a tank table output file that meets the aforementioned requirements.

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Executive Summary

The FREDYN semi-non-linear time domain ship motion and manoeuvring simulation program is currently used by the Defence Science and Technology Organisation (DSTO) to conduct platform motion predictions, analyses and evaluations. An important aspect of FREDYN's functionality is its ability to simulate the effects of internal flooding on the motion response of a ship, submarine or floating structure. This development has been achieved through the combined efforts of the Cooperative Research Navies (CRNAV) working group. The FREDYN flooding module requires a database of the platform's internal compartment and tank volumes to enable it to compute the instantaneous internal flooding water level, centre of mass, free-surface effect and other fluid volume specific parameters. This database is typically generated from a three-dimensional computer aided design (CAD) model of the platform and its internal volumes and is stored as an ASCII text data file. The file is referred to as a tank table or tank calibration file. To date, the database file is generated using third party software, in particular the Paramarine integrated naval architecture design and analysis program.

There is currently no restriction on which program or method is used to generate tank table database files, although the file format and content must meet the requirements specified by the Maritime Research Institute of the Netherlands (MARIN), the developers of FREDYN. Despite this relatively relaxed constraint, the CRNAV working group dictates that all flooding analyses conducted using FREDYN must be completed using a tank table file generated by an endorsed software program. Furthermore, in order to be accepted as an endorsed software program, the program must be shown to perform equally as well as or better than Paramarine at generating a tank table file and meet the data interface requirements prescribed by MARIN.

In 2010 the DSTO Maritime Platforms Division (now the Maritime Division) contracted Formation Design Systems Pty. Ltd. (FDS) to incorporate a tank table file generation capability within its ship stability and hydrostatics software program then known as Hydromax (now issued as Maxsurf Stability).

A study was conducted to determine if Maxsurf Stability is able, at a minimum, to meet the data content, format and quality requirements that will enable it to be endorsed by the CRNAV working group and used to support analyses conducted by DSTO.

The scope of the verification and validation analysis was limited to the tank calibration output file (*.OUT) generated by Maxsurf Stability. A simple box shaped barge with four internal tanks was used as the test case in accordance with the requirement specified by MARIN. Tank data were computed for the test case for a series of body-fixed rotations (heel and trim) in addition to the upright condition. The analysis was an objective evaluation of the tank calibration file's data content, format and quality against the data interface requirements specified by MARIN and a comparative tank table file generated by MARIN using Paramarine V7.1.

The results of the verification analysis indicates that the data content and format of the tank calibration file generated using Maxsurf Stability V20.00.01.59 meets all of the requirements specified by MARIN in their two interface requirements documents. The validation of the tank calibration data quality was completed by making a direct comparison against the data generated using Paramarine V7.1. The comparison indicated that there are several instances where the two data do not compare well and there is a significant relative error. An independent data set was generated using the three dimensional CAD modelling program Rhinoceros 3D V4.0 to provide an objective comparison between it and the Paramarine and Maxsurf Stability data.

A comparison between the Maxsurf Stability and Rhinoceros 3D data sets indicated that the data returned by Maxsurf Stability was predominantly (69%) accurate (with no relative error). There were limited instances (29%) where the data was found to be in error by less than one percent and only a few instances (2%) where the data was in error by more than one percent but less than five percent. These errors are attributed to both numerical rounding and the numerical discretization and integration method used by Maxsurf Stability.

Based on the analyses conducted and the results of the verification and validation study, it is recommended that Maxsurf Stability V20.00.01.59 be considered for acceptance and endorsed by MARIN and the CRNAV as a method for generating tank table database files.

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Contents

Acronyms and Abbreviations

ASCII	American Standard Code for Information Interchange
BL	Baseline
CI	Configuration Item
COMP	Compartment
CRNAV	Cooperative Research Navies
DSTO	Defence Science and Technology Organisation
FDS	Formation Design Systems Pty. Ltd.
FP	Forward Perpendicular
FS	Free-Surface Moment
GRC	Graphics Research Corporation
LCG	Longitudinal Centre of Gravity
MARIN	Maritime Research Institute of the Netherlands
PERM	Permeability
PS	Port Side
RE	Relative Error
S	Free-Surface Area
SB	Starboard Side
SHCP	Ship Hull Characteristics Program
STBD	Starboard
SYM	Symmetry
TCG	Transverse Centre of Gravity
V&V	Verification and Validation
VCG	Vertical Centre of Gravity

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1. Introduction

This report presents the methodology and results of the configuration item verification and validation (V&V) analysis of the Maxsurf Stability Advanced Version 20.00.01.59 (Maxsurf Stability) [1] tank calibration file generator. The independent V&V analysis was conducted within the Defence Science and Technology Organisation's (DSTO) Maritime Division. The purpose of the V&V analysis was to provide objective evidence that the Maxsurf Stability software can generate a tank calibration output file that meets the build-to requirements and the prescribed interface requirements that will enable its use with the existing semi-non-linear time domain ship motion simulation code, FREDYN [2].

1.1 Background

In recent years the Cooperative Research Navies (CRNAV) membership group has worked to develop a flooding module within FREDYN to investigate the effects of hull damage and subsequent flooding on a platform's motion response, stability and survivability. To enable these analyses, a database of the tank fluid volume properties is used in calculating the flow of water and air within the platform's compartments. The database is referred to by the Maritime Research Institute of the Netherlands (MARIN) as a Tank Table and in the context of Maxsurf Stability as a Tank Calibration file.

In 2010 DSTO contracted Formation Design Systems Pty. Ltd. (FDS), the developers of the Maxsurf suite of naval architectural modelling and analysis software, to develop a tank table database generator within their existing hydrostatics and stability analysis program (then known as Hydromax but recently renamed Maxsurf Stability). The functionality implemented by the developers allows the user to use the legacy tank and compartment modelling tools and tank calibration analysis routine to generate a set of tank data for a range of heel, trim and tank fill capacity conditions. This data is then able to be exported from Maxsurf Stability as a tank calibration file (tank table) for further processing using the MARIN Tank Table Processor. Once processed the output data is appropriate for use by the FREDYN flooding module.

1.2 Scope of the Verification and Validation

The scope of the V&V analysis was limited to the Maxsurf Stability generated tank calibration file (*.OUT file) containing tank calibration and compartment definition data. In the context of the analysis a *.OUT file is considered to be a discrete configuration item (CI). The V&V process did not consider the configuration or performance of the Maxsurf Stability software or its associated input data or the additional two FREDYN related files generated by the Maxsurf Stability software. The boundary of this V&V analysis is presented in Figure 1.

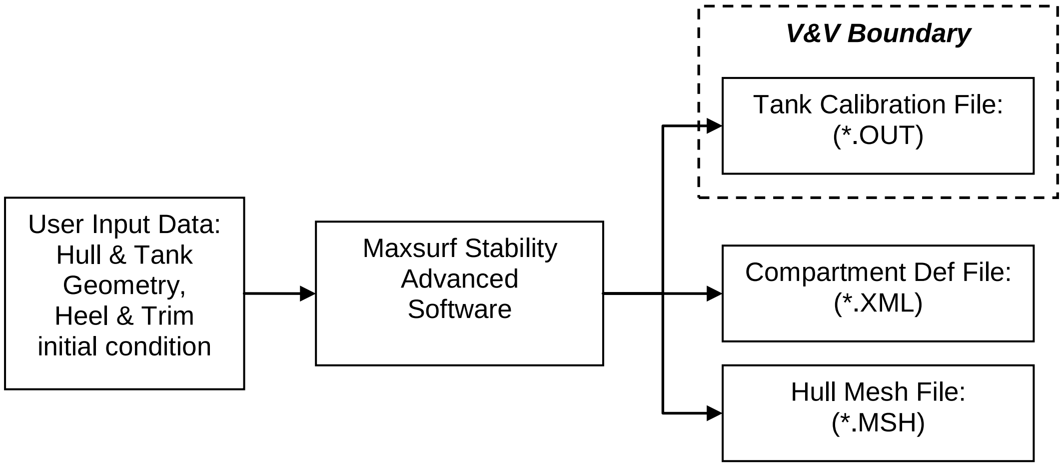

Figure 1 Configuration Item Verification and Validation boundary

1.3 Acceptance Criteria

The explicit acceptance criteria used in the V&V analysis was sourced from the following documents published by MARIN:

- Tank-Table Generation: Variable Definitions & Rotation Sequence Check [3]
- FREDYN-PARAMARINE Interface Requirements [4].

The requirement imposed by MARIN, as the developer of FREDYN, for accepting a method to generate tank table data files (including Maxsurf Stability) is that its performance is shown to be equal to or in excess of that currently provided by the GRC Paramarine software. In addition, the Maxsurf Stability data were compared against data generated using Rhinoceros 3D [5], a third-party computer aided design (CAD) modelling program. The results of the further comparison are provided as a means of co-validating the Maxsurf Stability data against an independent and objective data set. It is proposed that the acceptance criteria for the Maxsurf Stability generated tank calibration file, and hence the implicit methods used by Maxsurf Stability, be assessed on these two comparisons and based on the endorsed build-to requirements and objective data quality metrics.

The abovementioned data artefacts were used to:

- verify the format of the data output by Maxsurf Stability in the tank calibration output file
- validate the correctness of the data output by Maxsurf Stability in the tank calibration output file.

2. Verification and Validation Method

2.1 Test Case Model

Tank calibration files were generated for the MARIN barge benchmark model for the purpose of the V&V analysis. The MARIN box-shaped barge and its four internal tanks published by Ypma [3] were modelled using the Maxsurf Modeller Advanced version 18.03 [6] naval architecture and surface modelling software program (Figure 2). A series of tank calibration files were generated using Maxsurf Stability.

The MARIN barge and tank configuration is comprised of a simple box shaped hull geometry with four internal, identically sized, cube shaped tanks. This geometry has been modelled using Paramarine by researchers and software developers at MARIN to yield, among other data, tank calibration files. Consequently, existing tank calibration data and output files are available for comparison and reference purposes.

2.2 Verification of Data Format

The content and format of the Maxsurf Stability generated tank calibration file was verified against the requirements stated in the MARIN FREDYN-PARAMARINE Interface Requirements document [4]. The tank calibration file data was verified against the requirements set on a "complies/does not comply" basis. The common verification approach used was to inspect the tank calibration file and the Maxsurf Stability User Manual [7] and compare the observed data against the requirement set. The requirements verification matrix and results are presented in Appendix A.

2.3 Validation of Maxsurf Stability Generated Tank Calibration Data

The validation analysis of the Maxsurf Stability tank calibration file was completed by quantitatively comparing the numerical values computed and output in the calibration file (*.OUT) against the corresponding values determined using Paramarine (provided by Ypma [8]) and the solid modelling and volume properties calculator within the Rhinoceros 3D computer aided design software program (the objective reference data set). The analysis considered the starboard forward (SB Fwd) tank only. This was done to maintain consistency with the analysis approach and data presented by Ypma [3].

The MARIN barge SB Fwd tank was modelled in Rhinoceros 3D as a solid polyhedral for a range of tank filling levels and a range of heel and trim angles. The filling levels and heel and trim angles analysed correspond to those used by Ypma [3] and are presented in Section 3 of this report. The relative error between the Paramarine and Maxsurf Stability data and the Rhinceros 3D and Maxsurf Stability data were calculated for each parameter and test condition. The results of the validation study are presented in Appendix B and Appendix C for the Paramarine and Rhinoceros 3D comparisons respectively.

3. Validation Analysis

3.1 Coordinate System

The coordinate system used in the modelling, data calculation and reporting corresponds to the Ship Hull Characteristics Program (SHCP) output system presented on page 28 of Ypma [3]. The coordinate system requirement imposed on the tank calibration file (CI) is as follows: the coordinate system origin is located amidships, on the centreline and on the baseline (keel). The x axis is orientated parallel to the length of the barge and is positive forward; the y axis is orientated in the transverse direction and is positive to starboard; the z axis is orientated in the vertical direction and is positive upwards. This system results in a positive heel angle to starboard and a positive trim angle for a trim by the stern. The coordinate system is shown in Figure 2.

It is important to note that the barge's body-fixed coordinate system differs from the tank body fixed system described above. As presented by Ypma [3], the barge body-fixed coordinate system has the origin at the aft perpendicular, centreline and baseline. The directions of the principal axes are: x axis is positive forwards, the y axis is positive to port and the z axis is positive upwards.

3.2 Barge and Tank Model

The geometry of the barge and tanks is identical to that described by Ypma [3]. The rectangular barge is fitted with four identical tanks. Pairs of tanks are located at each end of the barge. The forward starboard (SB Fwd) tank, used as the subject of the validation analysis, is shown in Figure 2. The principal dimensions of the barge are presented in Table 1.

Table 1 MARIN Barge principal dimensions

Particular	Measurement
Length Overall	40.00 m
Beam	10.00 m
Depth	7.00 m
Draft	2.00 m

The majority of the SB Fwd tank's fluid volume properties are measured relative to the body-fixed datum (origin of the coordinate system) in accordance with the coordinate system presented in Section 3.1 and the reference conventions presented by Ypma [3]. The tanks' moments of inertia are calculated at the centre of volume of each tank using a coordinate system that is aligned with the tanks' body-fixed system.

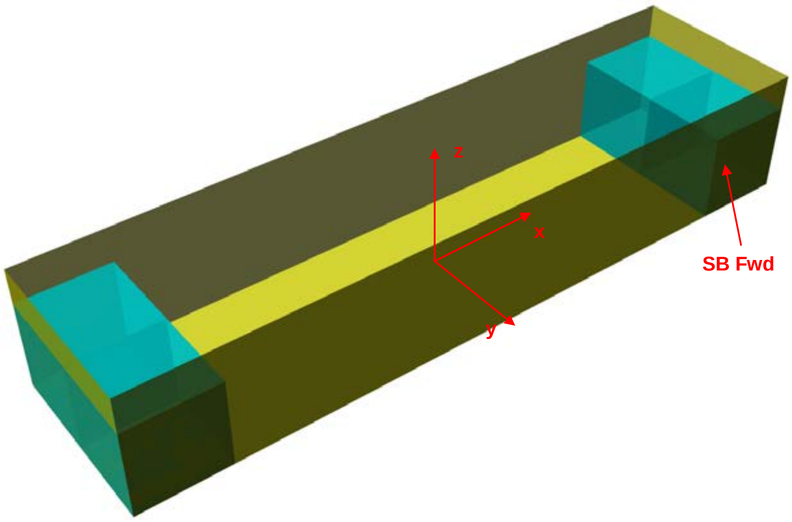

Figure 2 MARIN Barge model with four independent tanks. The body-fixed coordinate system shown corresponds to the tanks' (SHCP tank data output system).

3.3 Tank Particulars

The geometric particulars of the four tanks are listed below in Table 2.

Table 2 Tank geometric particulars

Particular	Measurement
Length	5.00 m
Breadth	5.00 m
Height	5.00 m
Capacity	125 m^3

The location of the geometric centre of the SB Fwd tank with zero fluid content and in the upright condition (no heel or trim) is presented in Table 3.

Table 3 SB Fwd tank geometric centre

Coordinate	Distance from Body-Fixed Datum
x	17.50 m
y	2.50 m
z	2.50 m

3.4 Heel and Trim Validation Analysis Matrix

A matrix of five heel and trim conditions corresponding to those presented by Ypma [3] was used to conduct the validation analysis of the tank fluid volume properties. The matrix is presented in Table 4.

Table 4 Heel and trim angle matrix used to conduct the validation analysis

Condition	Heel [deg]	Trim [deg]
No heel or trim	0.00	0.00
Heel to port only	-1.00	0.00
Heel to starboard only	1.00	0.00
Trim by the Head only	0.00	-1.00
Trim by the Stern only	0.00	1.00

3.5 Tank Capacity

A data set of tank volume properties were calculated for the five heel and trim angle combinations at five discrete tank capacities. The tank capacities analysed are a sub-set of the required capacities calculated by a tank table generator as stated in Ypma [4]. The tank capacities analysed are listed in Table 5. The density of the fluid in the tanks is 1 tonne per cubic metre.

Table 5 SB Fwd Tank partially filled conditions

Condition	Percentage Full [%]	Volume [m^3]
1	0.10	0.125
2	25.00	31.250
3	50.00	62.500
4	75.00	93.750
5	99.90	124.875

3.6 Tank Fluid Volume Properties

The following tank fluid volume properties were calculated and compared for each of the analysis conditions:

1. Sounding
2. Volume
3. Longitudinal Centre of Gravity (LCG)
4. Vertical Centre of Gravity (VCG)
5. Transverse Centre of Gravity (TCG)
6. Free-Surface Moment (FS)
7. Free-Surface Area (S)
8. Volume moment of inertia in x-x (Ixx)

9. Volume moment of inertia in y-y (Iyy)
10. Volume moment of inertia in z-z (Izz)
11. Product moment of inertia in x-y (Ixy)
12. Product moment of inertia in y-z (Iyz)
13. Product moment of inertia in x-z (Ixz).

The Capacity parameter of the tank was not explicitly analysed as the 1 tonne per cubic metre fluid density results in a Capacity of equal numerical value to the Volume. The Capacity results returned by Maxsurf Stability were found to be of an identical numerical value to the corresponding Volume results for all heel, trim and fill conditions.

3.7 Quantitative Analysis: Relative Error

The relative error (RE) of the Maxsurf Stability tank calibration data was calculated using the Paramarine and Rhinoceros 3D objective data set and Equation 1 shown below. In this instance, the 'Reference Data Set' corresponds to either the Paramarine or Rhinoceros 3D data set, depending on the comparison.

$$\mathrm{RE} = \frac{\text{Reference Data Set} - \text{Maxsurf Stability}}{\text{Reference Data Set}} \times 100 \qquad \textit{Equation 1}$$

A colour indicator system was used to distinguish the magnitude of the relative error of the Maxsurf Stability (and Paramarine) generated data. The indicator system and its prescribed relative error ranges are presented in Table 6.

Table 6 Colour map indication of relative error

Relative Error Range	Colour Indicator
RE < ±1%	
±1% ≤ RE ≤ ±5%	
±5% ≤ RE ≤ ±25%	
RE > ±25%	

4. Analysis Outcomes and Discussion

4.1 Verification Analysis

The results of the verification analysis presented in Appendix A show that the Maxsurf Stability program is successful in generating a tank calibration file (tank table) that complies with the build-to requirements prescribed by MARIN. In addition to this, the MARIN Tank Table Processor V1.1 was successful in importing, processing and exporting the Maxsurf Stability generated tank calibration files.

4.2 Validation Analyses

The results of the quantitative analysis and validation of the Maxsurf Stability generated tank calibration file has indicated a number of issues. The comparison between the Paramarine V7.1 and Maxsurf Stability data has shown significant relative errors in the following data:

1. Sounding data for the two trim conditions and all fill conditions
2. Longitudinal Centre of Gravity (LCG) data for both trim conditions and all fill conditions (this error is most noticeable for the 0.1 percent fill condition and becomes less significant as the fill level increases, nonetheless, the error is still apparent)
3. Transverse Centre of Gravity (TCG) data for all heel, trim and fill conditions
4. Free-surface data for all heel, trim and fill conditions
5. product moments of inertia (Iyz and Ixz) for the two heel conditions and all fill conditions.

The cause of these issues has been identified as two discrepancies between the Paramarine data and the coordinate system requirements prescribed by Ypma [3]. The identified causes that explain the relative errors observed in the validation analysis are:

1. The tank body-fixed sign convention that underpins the Paramarine data does not comply with the system described by Ypma [3]. The sign (positive or negative) of the Paramarine data corresponds to a convention system where the transverse direction is positive to port and a trim by the bow is positive. The tank body-fixed coordinate system prescribed by Ypma [3] requires the transverse axis to be positive to starboard and the trim angle to be positive for a trim by the stern. These two discrepancies explain the significant relative errors observed for the Sounding, LCG, TCG, Iyz and Ixz data. It should be noted that if these two coordinate system discrepancies are corrected, the result is that the Paramarine and Maxsurf Stability data (Sounding, LCG, TCG, Iyz and Ixz) are in agreement and show minimal or no relative error.
2. Paramarine does not return a calculated value for the free-surface moment parameter whereas Maxsurf Stability does. Consequently, the comparison between Paramarine and Maxsurf Stability results in an infinite relative error and the meaningful validation of this data cannot be achieved. A result of 'Cannot Be Assessed" has been recorded for these comparisons in Table B6 to Table B10 inclusive in Appendix B.

In addition to these discrepancies, it was also observed that the Paramarine tank table file Input Compartment Definitions data did not match the corresponding example data presented by Ypma [3]. Details of these discrepancies are presented in Figure 3, Figure 4 and Figure 5.

7.2 Coordinate system check

Taking the same SB forward tank for the lowest level (0.1% filling) gives the following values in the SHCP table:

Heel [deg]	Trim [deg]	Sounding [m]	LCG [m]	TCG [m]	VCG [m]
0	0	0.01	17.50	2.50	0.00
-1	0	0.02	17.50	0.33	0.01
1	0	-0.07	17.50	4.67	0.01
0	-1	-0.33	19.67	2.50	0.01
0	1	0.28	15.33	2.50	0.01

These values can be used as a check of the coordinate system. By setting the heel 1 [deg] (starboard down), the centre of gravity will shift to starboard. This is correctly shown by the positive TCG of 4.67 [m] (y positive to starboard). If the heel changes to -1 [deg] (port down), then the centre of gravity will shift to the centreline (shown by the 0.33 [m].
The same check can be done for the trim angle. For a positive angle of 1 [deg] (stern down) the cog shifts to the aft of the tank (LCG of 15.33 [m]), for a trim value of -1 [deg] (bow down), the LCG shifts to 19.67 [m], which is also correct. These values will be slightly different if an empty tank is represented by a filling percentage of 0%, nevertheless, the trend should be very clear.
The sign of the sounding values is also correct (see Figure 7).

Figure 3 Coordinate system check: coordinate and rotation system description and reference example indicating heel and trim conditions and resultant sign convention of Sounding, LCG, TCG and VCG [3]. Refer to Table B1 to B5 inclusive to see Paramarine V7.1 results and the discrepancy in TCG tank data.

6.3 Compartment Bounding-Boxes

In addition to these tables the bounding box of each compartment is written by Paramarine to the same file. This data is used for visualization of the compartments and their floodwater in the FREDYN GUI.

Table 2 Example of compartment bounding box information

```
INPUT COMPARTMENT DESCRIPTIONS

ID         NAME              SYM PERM   X1D    X2D     Y1D     Y2D     Z1D     Z2D  ROFF

201 Tank_PS_Fwd               -1 1.00   0.00   5.00    0.00    5.00    0.00    5.00   0
202 Tank_SB_Fwd                1 1.00   0.00   5.00   -5.00    0.00    0.00    5.00   0
203 Tank_PS_Aft               -1 1.00  35.00  40.00    0.00    5.00    0.00    5.00   0
204 Tank_SB_Aft                1 1.00  35.00  40.00   -5.00    0.00    0.00    5.00   0
1SHIP-
```

Figure 4 Tank Table compartment bounding box data description and example for the MARIN box barge [3].

barge_tank - Notepad

File Edit Format View Help

```
 DESIGN DRAFT   (+ ABOVE BL)      2.000  M
 DESIGN TRIM    (+ BY STERN)      0.000  M
 LENGTH BETWEEN PERPENDICULARS   40.000 METERS

                Approximate Bounding Cube Values:
      ---------------------------------------------------
         Forward X location             40.000  M (+Aft FP)
         After   X location             -0.000  M (+Aft FP)
         PORT    Y value on Station      5.000  M
         STBD    Y value on Station     -5.000  M
         Lowest  Z value on Station      0.000  M (+Abv BL)
         Highest Z value on Station      7.000  M (+Abv BL)

                        INPUT COMPARTMENT DESCRIPTIONS

  ID         NAME              SYM PERM   X1D    X2D     Y1D     Y2D     Z1D     Z2D  ROFF

 201 Tank_PS_Fwd                1 1.00  20.00  15.00    0.00    5.00    0.00    5.00   0
 202 Tank_SB_Fwd                1 1.00  20.00  15.00   -5.00    0.00    0.00    5.00   0
 203 Tank_PS_Aft                1 1.00 -15.00 -20.00    0.00    5.00    0.00    5.00   0
 204 Tank_SB_Aft                1 1.00 -15.00 -20.00   -5.00    0.00    0.00    5.00   0
1SHIP-
```

Figure 5 Tank Table compartment bounding box data generated using Paramarine V7.1 (validation data set) provided by Ypma [8]. Highlighted text entries indicate the discrepancy when compared to MARIN requirements document example (Figure 4).

Notwithstanding the observed discrepancies, only minimal relative error (RE < ±1 percent) was observed for a minor number of the remaining tank parameters and test conditions. These instances constitute only 24% of the total comparisons made. The source of these differences can be attributed to the rounding (precision) and integration errors inherent in the routines used in these computer programs.

The results of the comparison between Maxsurf Stability and Rhinoceros 3D data (Appendix C) indicate that Maxsurf Stability is successful in calculating and outputting accurate tank data. Of the thirteen parameters, five heel and trim conditions and five fill levels tested for the SB Fwd tank, the analysis indicated that: 69% were error free; 29%

were in error by less than ±1 percent; and 2% were in error by less than ±5 percent but more than ±1 percent. Similar to the Paramarine and Maxsurf Stability comparison, the sources of these errors are most likely to be the numerical rounding of the results and the level of discretization used in the numerical integration technique programmed in Maxsurf Stability. In five of the six results that were in error by more than ±1 percent the error can be attributed to the numerical rounding. In these cases, the magnitude of the difference between the Maxsurf Stability data and the objective data is large relative to the absolute value of the result. This exacerbates the size of the error. Nonetheless, the result of the Maxsurf Stability – Rhinoceros 3D validation analysis provides evidence that the Maxsurf Stability program can successfully generate accurate tank table data.

5. Recommendations and Concluding Remarks

The results of the V&V analyses of the Maxsurf Stability generated test case tank calibration output file are that the output file, and therefore the file generation application within Maxsurf Stability:

1. has been shown to meet all of the verification requirements set out in the FREDYN developer's verification requirements documentation ([3, 4])
2. was successfully processed using the MARIN Tank Table Processor V1.0, thereby verifying the file's data format
3. has been shown to not match all of the data output in the validation reference tank table file generated using Paramarine V7.1
4. has been shown to match, with minimal relative error, the tank parameter objective data set generated using Rhinoceros 3D.

Based on the outcomes of the verification and validation analyses presented in this report and the related acceptance criteria imposed by MARIN, it is recommended that the Maxsurf Stability (Version 20.00.01.59) software program be considered for acceptance by MARIN and the Cooperative Research Navies working group as a method for generating tank tables for use with FREDYN.

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Appendix A: Tank Table Output File Verification Matrix

Table A1 Tank Calibration File data format verification matrix: requirements transposed from the FREDYN interface requirements document presented by Ypma [4]

Req ID	Document Section	Document Section Title	Document Sub-Section	Document Sub-Section Title	Requirement	Verification Method	Compliance	Verification Evidence	Comment
1-1	2	Tank Tables	2.1	Heel & Trim Values	The heel definition for each table is defined as positive for Port down	Not assessed	Not assessed	Not assessed	This requirement is in conflict with requirement 2-2 (Table A2). Clarification was sought from MARIN and the outcome is that requirement 2-2 takes precedence [9].
1-2	2	Tank Tables	2.1	Heel & Trim Values	The trim definition is defined as positive for stern down	Inspection	Compliant	For Maxsurf Stability generated output files: 1.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 1 Trim.OUT] and -1.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel -1 Trim.OUT]. With respect to Tank 102 Fwd SB: Where the trim angle is recorded in the output file as (positive) 1 deg, the tank sounding exceeds 5.00 m (the top of the tank) with respect to the sounding tube datum (midships, centreline, keel) indicating that the barge has trimmed upwards at the bow. Conversely, for the recorded trim angle of -1.00 deg, the tank sounding does not exceed 5.00 m, thus indicating that the barge is trimmed downwards at the bow.	This convention complies with the SHCP coordinate system reported in Rosborough [10].
1-3	2	Tank Tables	2.2	Volume Range	The contents of a single tank have to be described by a percentage ranging from 0% (empty tank) to 100% (full tank)	Inspection	Compliant	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. The tank data is recorded for each tank for varying contents ranging from 0% to 100% full inclusive. The % FULL data is the leading column in the output file for each tank.	No Comment.
1-4	2	Tank Tables	2.3	Free Surface Area Column	Each tank-table shall have an additional column giving the free surface area as a function of the filling percentage.	Inspection	Compliant	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. The area of the free surface is recorded in the tank data table. The area of the free surface (denoted as S) is recorded for each tank for all % FULL. The free surface area data is recorded in the ninth (9th) column in the output file for each tank.	No Comment.
1-5	2	Tank Tables	2.4	Tank Mass Moment of Inertia Columns	Each tank-table shall have an additional column giving the free surface moment of inertia as a function of the filling percentage.	Inspection	Compliant	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. The free surface area moment of inertia is recorded in the tank data table. The free surface area moment of inertia (denoted as FS) is recorded for each tank for all % FULL. The free surface area moment of inertia data is recorded in the eighth (8th) column in the output file for each tank.	No Comment.

Req ID	Document Section	Document Section Title	Document Sub-Section	Document Sub-Section Title	Requirement	Verification Method	Compliance	Verification Evidence	Comment
1-6	2	Tank Tables	2.4	Tank Mass Moment of Inertia Columns	The table format will be completed with 6 columns in the following order (left to right): 1. Ixx 2. Iyy 3. Izz 4. Ixy 5. Iyz 6. Ixz	Inspection	Compliant	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. The tank mass moments of inertia (Ixx, Iyy, Izz, Ixy, Iyz, Ixz) are recorded in the tank data table in the aforementioned order. The tank mass moments of inertia are recorded for each tank for all % FULL. The tank mass moments of inertia data is recorded in the last six (6) columns in the output file for each tank (Column 10 through 15).	No Comment.
1-7	2	Tank Tables	2.5	Summary	A single tank-table will have the following columns: FULL SOUNDING VOLUME CAPACITY LCG TCG VCG S Ixx Iyy Izz Ixy Iyz Ixz	Inspection	Compliant	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. The tank table contains the following columns (listed in sequence): FULL, SOUNDING, VOLUME, CAPACITY, LCG, VCG, TCG, FS, S, Ixx, Iyy, Izz, Ixy, Iyz, Ixz.	Note that there is no FS column listed in the requirement [4]. This requirement is assumed to be an '*as a minimum*' type requirement.
1-8	2	Tank Tables	2.5	Summary	The unit of the 'mass moment of inertia' is given in [m^5]	Inspection	Compliant	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. The tank mass moments of inertia (Ixx, Iyy, Izz, Ixy, Iyz, Ixz) are recorded in the tank data table with the unit of [m^5].	No Comment.
1-9	2	Tank Tables	2.5	Summary	The unit of the 'mass moment of inertia' [m^5] has to be calculated as such	Inspection	Compliant	Evidence of calculation methods and algorithms has been supplied by the Developer and is presented in Appendix F. The algorithms illustrate the use of the volume moments method for calculating the volume moment of inertia with the result being in the units of m^5. Noting that the 'mass moment of inertia' stated in the requirement is a pseudo-mass and is independent of fluid density, consequently resulting in a m^5 output.	No Comment.
1-10	3	Geometry Information	3.3	Tank Data	For each tank in the XML file there has to be a corresponding tank-table in the tank table file	Inspection	Compliant	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. For each tank in the *.XML file (generated for the Barge using Maxsurf Stability) there is a corresponding tank-table in the tank table (*.OUT) file.	No Comment.

Table A2 Tank Calibration File data format verification matrix: requirements transposed from the FREDYN variable definitions and rotation sequence check document presented by Ypma [3]

Req ID	Document Section	Document Section Title	Document Sub-Section	Document Sub-Section Title	Requirement	Verification Method	Compliance	Verification Evidence	Comment
2-1	6.2	Tank Table Format	6.2.1	SHCP Original	The tank tables are generated in the SHCP format.	Inspection	Complies	For Maxsurf Stability generated output files: 1.00 deg heel [Filename: Maxsurf Stability Tank Table Verification 1 Heel 0 Trim.OUT] the data format contained in the file matches the SHCP format presented in Section 6.2.1 Table 1 and Section 6.3 Table 2 and the associated Extension described in Section 6.2.2 [3]	Additional verification evidence: the Maxsurf Stability tank calibration output file was successfully read in, reviewed and processed using the MARIN Tank Table Processor Version 1.1.
2-2	6.2	Tank Table Format	6.2.1	SHCP Original	Based on the information provided in [3], the following SHCP output body fixed coordinate system is required: The origin occurs at amidhsips, centreline and baseline (keel). The positive directions of the principal axes are: x is positive forward of amidships, y is positive to starboard, z is positive upwards.	Inspection	Complies	For Maxsurf Stability generated output files: 1.00 deg heel [Filename: Maxsurf Stability Tank Table Verification 1 Heel 0 Trim.OUT] and -1.00 deg heel [Filename: Maxsurf Stability Tank Table Verification -1 Heel 0 Trim.OUT]. With respect to Tank 102 Fwd SB: The output centre of volume for an upright barge condition has positive values of LCG, TCG and VCG indicating that the point of the centre of volume is positive forward of amidships, positive to starboard and positive above the baseline.	
2-3	6.5	Quality Definition	Table Item 1	Description	The filling percentage has to be defined from 0% to 100%	Inspection	Complies	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. The tank data is recorded for each tank for varying contents ranging from 0% to 100% full inclusive. The % FULL data is the leading column in the output file for each tank.	See Req 1-3
2-4	6.5	Quality Definition	Table Item 2	Description	Strictly ascending level with increasing volume	Inspection	Complies	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. The tank data is recorded for each tank for varying contents ranging from 0% to 100% full inclusive in ascending order.	
2-5	6.5	Quality Definition	Table Item 3	Description	All tables have to be 100% filled	Inspection	Complies	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. The tank data is recorded for each tank for varying filling values ranging from 0% to 100% inclusive.	
2-6	6.5	Quality Definition	Table Item 4	Description	All tables have to be the same size	Inspection	Complies	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. The tank tables generated in the tank calibration output file are of identical size for all tanks/tables.	Refer to Appendix C to view the contents of the Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT file.
2-7	6.5	Quality Definition	Table Item 5	Description	Compartment info shall be included	Inspection	Complies	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. The compartment information is contained in the output file under the header INPUT COMPARTMENT DESCRIPTIONS (starting at line 14).	Refer to Appendix C to view the input compartment description data and location within the output file.

Req ID	Document Section	Document Section Title	Document Sub-Section	Document Sub-Section Title	Requirement	Verification Method	Compliance	Verification Evidence	Comment
2-8	6.5	Quality Definition	Table Item 6	Description	Reliable 'smooth' free surface area	Analysis and inspection	Complies	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 1.00 deg heel, 0.00 deg trim and 60.00 deg heel, 0.00 deg trim. The Maxsurf Stability tank calibration files were imported and processed using the MARIN Tank Table Processor V1.1 and the free-surface area (S) was plotted as a function of filling percentage. The plotted data possessed a smooth form and the smoothness of the data was found to be reliable as it was observed for a range of heel and trim conditions.	Refer to Appendix E for the plots of the SB Fwd tank free-surface area versus filling percentage for starboard heel angles of 1 degree and 60 degrees.
2-9	6.5	Quality Definition	Table Item 7	Description	'tankTableProcessor' application is the format checker	Execution and inspection	Complies	For Maxsurf Stability generated output files: Observed for all generated files but for evidence 0.00 deg heel, 0.00 deg trim [Filename: Maxsurf Stability Tank Table Verification 0 Heel 0 Trim.OUT]. All MARIN barge tank calibration files generated using Maxsurf Stability were successfully opened, reviewed and processed using Tank Table Processor Version 1.1.	

Appendix B: Maxsurf Stability Tank Calibration Output File – Comparison with Paramarine V7.1 Data

B.1. Comparison of Maxsurf Stability against Paramarine V7.1: Volume, Sounding, LCG, VCG and TCG

Table B1 SB FWD Tank at 0.10% Full.

		Maxsurf Stability Advanced: V20.00.01.59					Paramarine V7.1					Relative Error				
Heel [deg]	Trim [deg]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [%]	Sounding [%]	LCG [%]	VCG [%]	TCG [%]
0.00	0.00	0.12	0.01	17.50	0.00	2.50	0.13	0.01	17.50	0.00	-2.50	-8.33	0.00	0.00	0.00	200.00
-1.00	0.00	0.12	0.03	17.50	0.01	0.56	0.13	0.03	17.50	0.01	-0.56	-8.33	0.00	0.00	0.00	200.00
1.00	0.00	0.12	-0.06	17.50	0.01	4.44	0.13	-0.06	17.50	0.01	-4.44	-8.33	0.00	0.00	0.00	200.00
0.00	-1.00	0.12	-0.32	19.43	0.01	2.50	0.13	0.29	15.56	0.01	-2.50	-8.33	210.34	-24.86	0.00	200.00
0.00	1.00	0.12	0.29	15.57	0.01	2.50	0.13	-0.32	19.44	0.01	-2.50	-8.33	190.63	19.92	0.00	200.00

Table B2 SB FWD Tank at 25% Full.

		Maxsurf Stability Advanced: V20.00.01.59					Paramarine V7.1					Relative Error				
Heel [deg]	Trim [deg]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [%]	Sounding [%]	LCG [%]	VCG [%]	TCG [%]
0.00	0.00	31.25	1.25	17.50	0.63	2.50	31.25	1.25	17.50	0.63	-2.50	0.00	0.00	0.00	0.00	200.00
-1.00	0.00	31.25	1.29	17.50	0.63	2.47	31.25	1.29	17.50	0.63	-2.47	0.00	0.00	0.00	0.00	200.00
1.00	0.00	31.25	1.21	17.50	0.63	2.53	31.25	1.21	17.50	0.63	-2.53	0.00	0.00	0.00	0.00	200.00
0.00	-1.00	31.25	0.94	17.53	0.63	2.50	31.25	1.56	17.47	0.63	-2.50	0.00	39.74	-0.34	0.00	200.00
0.00	1.00	31.25	1.56	17.47	0.63	2.50	31.25	0.94	17.53	0.63	-2.50	0.00	-65.96	0.34	0.00	200.00

Table B3 SB FWD Tank at 50% Full.

		Maxsurf Stability Advanced: V20.00.01.59					Paramarine V7.1					Relative Error				
Heel [deg]	Trim [deg]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [%]	Sounding [%]	LCG [%]	VCG [%]	TCG [%]
0.00	0.00	62.49	2.50	17.50	1.25	2.50	62.50	2.50	17.50	1.25	-2.50	-0.02	0.00	0.00	0.00	200.00
-1.00	0.00	62.49	2.54	17.50	1.25	2.49	62.50	2.54	17.50	1.25	-2.49	-0.02	0.00	0.00	0.00	200.00
1.00	0.00	62.49	2.46	17.50	1.25	2.51	62.50	2.46	17.50	1.25	-2.51	-0.02	0.00	0.00	0.00	200.00
0.00	-1.00	62.49	2.19	17.51	1.25	2.50	62.50	2.81	17.49	1.25	-2.50	-0.02	-28.31	-0.11	0.00	200.00
0.00	1.00	62.49	2.81	17.49	1.25	2.50	62.50	2.19	17.51	1.25	-2.50	-0.02	22.06	0.11	0.00	200.00

Table B4 SB FWD Tank at 75% Full.

		Maxsurf Stability Advanced: V20.00.01.59					Paramarine V7.1					Relative Error				
Heel [deg]	Trim [deg]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [%]	Sounding [%]	LCG [%]	VCG [%]	TCG [%]
0.00	0.00	93.74	3.75	17.50	1.88	2.50	93.75	3.75	17.50	1.88	-2.50	-0.01	0.00	0.00	0.00	200.00
-1.00	0.00	93.74	3.79	17.50	1.88	2.49	93.75	3.79	17.50	1.88	-2.49	-0.01	0.00	0.00	0.00	200.00
1.00	0.00	93.74	3.71	17.50	1.88	2.51	93.75	3.71	17.50	1.88	-2.51	-0.01	0.00	0.00	0.00	200.00
0.00	-1.00	93.74	3.44	17.51	1.88	2.50	93.75	4.06	17.49	1.88	-2.50	-0.01	15.27	-0.11	0.00	200.00
0.00	1.00	93.74	4.06	17.49	1.88	2.50	93.75	3.44	17.51	1.88	-2.50	-0.01	-18.02	0.11	0.00	200.00

Table B5 SB FWD Tank at 99.9% Full.

		Maxsurf Stability Advanced: V20.00.01.59					Paramarine V7.1					Relative Error				
Heel [deg]	Trim [deg]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [%]	Sounding [%]	LCG [%]	VCG [%]	TCG [%]
0.00	0.00	124.86	5.00	17.50	2.50	2.50	124.88	5.00	17.50	2.50	-2.50	-0.02	0.00	0.00	0.00	200.00
-1.00	0.00	124.86	5.06	17.50	2.50	2.50	124.88	5.06	17.50	2.50	-2.50	-0.02	0.00	0.00	0.00	200.00
1.00	0.00	124.86	4.97	17.50	2.50	2.50	124.88	4.97	17.50	2.50	-2.50	-0.02	0.00	0.00	0.00	200.00
0.00	-1.00	124.86	4.71	17.50	2.50	2.50	124.88	5.32	17.50	2.50	-2.50	-0.02	11.47	0.00	0.00	200.00
0.00	1.00	124.86	5.32	17.50	2.50	2.50	124.88	4.71	17.50	2.50	-2.50	-0.02	-12.95	0.00	0.00	200.00

B.2. Comparison of Maxsurf Stability against Paramarine V7.1: Free-Surface Moment and Free-Surface Area

Table B6 SB FWD Tank at 0.10% Full.

		Maxsurf Stability Advanced: V20.00.01.59		Paramarine V7.1		Relative Error	
Heel [deg]	Trim [deg]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [%]	Free-Surface Area [%]
0.00	0.00	52.08	25.00	0.00	25.00	Cannot Be Assessed	0.00
-1.00	0.00	2.02	8.46	0.00	8.44	Cannot Be Assessed	-0.24
1.00	0.00	2.02	8.46	0.00	8.44	Cannot Be Assessed	-0.24
0.00	-1.00	17.79	8.54	0.00	8.44	Cannot Be Assessed	-1.18
0.00	1.00	17.54	8.42	0.00	8.44	Cannot Be Assessed	0.24

Table B7 SB FWD Tank at 25% Full.

		Maxsurf Stability Advanced: V20.00.01.59		Paramarine V7.1		Relative Error	
Heel [deg]	Trim [deg]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [%]	Free-Surface Area [%]
0.00	0.00	52.08	25.00	0.00	25.00	Cannot Be Assessed	0.00
-1.00	0.00	52.10	25.00	0.00	25.00	Cannot Be Assessed	0.00
1.00	0.00	52.10	25.00	0.00	25.00	Cannot Be Assessed	0.00
0.00	-1.00	52.09	25.00	0.00	25.00	Cannot Be Assessed	0.00
0.00	1.00	52.09	25.00	0.00	25.00	Cannot Be Assessed	0.00

Table B8 SB FWD Tank at 50% Full.

		Maxsurf Stability Advanced: V20.00.01.59		Paramarine V7.1		Relative Error	
Heel [deg]	Trim [deg]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [%]	Free-Surface Area [%]
0.00	0.00	52.08	25.00	0.00	25.00	Cannot Be Assessed	0.00
-1.00	0.00	52.10	25.00	0.00	25.00	Cannot Be Assessed	0.00
1.00	0.00	52.10	25.00	0.00	25.00	Cannot Be Assessed	0.00
0.00	-1.00	52.09	25.00	0.00	25.00	Cannot Be Assessed	0.00
0.00	1.00	52.09	25.00	0.00	25.00	Cannot Be Assessed	0.00

Table B9 SB FWD Tank at 75% Full.

		Maxsurf Stability Advanced: V20.00.01.59		Paramarine V7.1		Relative Error	
Heel [deg]	Trim [deg]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [%]	Free-Surface Area [%]
0.00	0.00	52.08	25.00	0.00	25.00	Cannot Be Assessed	0.00
-1.00	0.00	52.10	25.00	0.00	25.00	Cannot Be Assessed	0.00
1.00	0.00	52.10	25.00	0.00	25.00	Cannot Be Assessed	0.00
0.00	-1.00	52.09	25.00	0.00	25.00	Cannot Be Assessed	0.00
0.00	1.00	52.09	25.00	0.00	25.00	Cannot Be Assessed	0.00

Table B10 SB FWD Tank at 99.9% Full.

		Maxsurf Stability Advanced: V20.00.01.59		Paramarine V7.1		Relative Error	
Heel [deg]	Trim [deg]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [%]	Free-Surface Area [%]
0.00	0.00	52.08	25.00	0.00	25.00	Cannot Be Assessed	0.00
-1.00	0.00	2.02	8.46	0.00	8.44	Cannot Be Assessed	-0.24
1.00	0.00	2.02	8.46	0.00	8.44	Cannot Be Assessed	-0.24
0.00	-1.00	17.54	8.42	0.00	8.44	Cannot Be Assessed	0.24
0.00	1.00	17.79	8.54	0.00	8.44	Cannot Be Assessed	-1.18

B.3. Comparison of Maxsurf Stability against Paramarine V7.1: Volume moments of inertia (I_{xx}, I_{yy} and I_{zz}) and Product moments of inertia (I_{xy}, I_{yz} and I_{xz})

Table B11 SB FWD Tank at 0.10% Full.

		Maxsurf Stability Advanced: V20.00.01.59						Paramarine V7.1						Relative Error					
Heel [deg]	Trim [deg]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [%]	I_{yy} [%]	I_{zz} [%]	I_{xy} [%]	I_{yz} [%]	I_{xz} [%]
0.00	0.00	0.26	0.26	0.52	0.00	0.00	0.00	0.26	0.26	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-1.00	0.00	0.02	0.26	0.28	0.00	0.00	0.00	0.02	0.26	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	200.00	0.00
1.00	0.00	0.02	0.26	0.28	0.00	0.00	0.00	0.02	0.26	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	200.00	0.00
0.00	-1.00	0.26	0.02	0.28	0.00	0.00	0.00	0.26	0.02	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.26	0.02	0.28	0.00	0.00	0.00	0.26	0.02	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B12 SB FWD Tank at 25% Full.

		Maxsurf Stability Advanced: V20.00.01.59						Paramarine V7.1						Relative Error					
Heel [deg]	Trim [deg]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [%]	I_{yy} [%]	I_{zz} [%]	I_{xy} [%]	I_{yz} [%]	I_{xz} [%]
0.00	0.00	69.17	69.36	130.39	0.00	0.00	0.00	69.17	69.17	130.21	0.00	0.00	0.00	0.00	-0.27	-0.14	0.00	0.00	0.00
-1.00	0.00	69.18	69.34	130.36	0.00	0.57	0.00	69.16	69.18	130.18	0.00	-0.57	0.00	-0.03	-0.23	-0.14	0.00	200.00	0.00
1.00	0.00	69.18	69.34	130.36	0.00	-0.57	0.00	69.16	69.18	130.18	0.00	0.57	0.00	-0.03	-0.23	-0.14	0.00	200.00	0.00
0.00	-1.00	69.18	69.34	130.36	0.00	0.00	0.57	69.18	69.16	130.18	0.00	0.00	0.57	0.00	-0.26	-0.14	0.00	0.00	0.00
0.00	1.00	69.18	69.34	130.36	0.00	0.00	-0.57	69.18	69.16	130.18	0.00	0.00	-0.57	0.00	-0.26	-0.14	0.00	0.00	0.00

Table B13 SB FWD Tank at 50% Full.

		Maxsurf Stability Advanced: V20.00.01.59						Paramarine V7.1						Relative Error					
Heel [deg]	Trim [deg]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [%]	I_{yy} [%]	I_{zz} [%]	I_{xy} [%]	I_{yz} [%]	I_{xz} [%]
0.00	0.00	162.74	163.13	260.77	0.00	0.00	0.00	162.76	162.76	260.42	0.00	0.00	0.00	0.01	-0.23	-0.13	0.00	0.00	0.00
-1.00	0.00	162.76	163.13	260.76	0.00	1.14	0.00	162.77	162.78	260.40	0.00	-1.14	0.00	0.01	-0.22	-0.14	0.00	200.00	0.00
1.00	0.00	162.76	163.13	260.76	0.00	-1.14	0.00	162.77	162.78	260.40	0.00	1.14	0.00	0.01	-0.22	-0.14	0.00	200.00	0.00
0.00	-1.00	162.76	163.13	260.76	0.00	0.00	1.14	162.78	162.77	260.40	0.00	0.00	1.14	0.01	-0.22	-0.14	0.00	0.00	0.00
0.00	1.00	162.76	163.13	260.76	0.00	0.00	-1.14	162.78	162.77	260.40	0.00	0.00	-1.14	0.01	-0.22	-0.14	0.00	0.00	0.00

Table B14 SB FWD Tank at 75% Full.

		Maxsurf Stability Advanced: V20.00.01.59						Paramarine V7.1						Relative Error					
Heel [deg]	Trim [deg]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [%]	I_{yy} [%]	I_{zz} [%]	I_{xy} [%]	I_{yz} [%]	I_{xz} [%]
0.00	0.00	305.15	305.72	391.16	0.00	0.00	0.00	305.18	305.18	390.63	0.00	0.00	0.00	0.01	-0.18	-0.14	0.00	0.00	0.00
-1.00	0.00	305.18	305.74	391.15	0.00	1.70	0.00	305.20	305.21	390.62	0.00	-1.70	0.00	0.01	-0.17	-0.14	0.00	200.00	0.00
1.00	0.00	305.18	305.74	391.15	0.00	-1.70	0.00	305.20	305.21	390.62	0.00	1.70	0.00	0.01	-0.17	-0.14	0.00	200.00	0.00
0.00	-1.00	305.18	305.74	391.15	0.00	0.00	1.71	305.21	305.20	390.62	0.00	0.00	1.70	0.01	-0.18	-0.14	0.00	0.00	-0.59
0.00	1.00	305.18	305.74	391.15	0.00	0.00	-1.71	305.21	305.20	390.62	0.00	0.00	-1.70	0.01	-0.18	-0.14	0.00	0.00	-0.59

Table B15 SB FWD Tank at 99.9% Full.

		Maxsurf Stability Advanced: V20.00.01.59						Paramarine V7.1						Relative Error					
Heel [deg]	Trim [deg]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [%]	I_{yy} [%]	I_{zz} [%]	I_{xy} [%]	I_{yz} [%]	I_{xz} [%]
0.00	0.00	519.74	520.51	521.03	0.00	0.00	0.00	519.79	519.79	520.31	0.00	0.00	0.00	0.01	-0.14	-0.14	0.00	0.00	0.00
-1.00	0.00	519.75	520.28	520.80	0.00	0.60	0.00	519.57	519.80	520.09	0.00	-0.60	0.00	-0.03	-0.09	-0.14	0.00	200.00	0.00
1.00	0.00	519.75	520.28	520.80	0.00	-0.60	0.00	519.57	519.80	520.09	0.00	0.60	0.00	-0.03	-0.09	-0.14	0.00	200.00	0.00
0.00	-1.00	519.75	520.28	520.80	0.00	0.00	0.60	519.80	519.57	520.09	0.00	0.00	0.60	0.01	-0.14	-0.14	0.00	0.00	0.00
0.00	1.00	519.75	520.28	520.80	0.00	0.00	-0.60	519.80	519.57	520.09	0.00	0.00	-0.60	0.01	-0.14	-0.14	0.00	0.00	0.00

Appendix C: Maxsurf Stability Tank Calibration Output File – Comparison with Rhinoceros 3D V4.0 Data

C.1. Comparison of Rhinoceros 3D V4.0 against Maxsurf Stability: Volume, Sounding, LCG, VCG and TCG

Table C1 SB FWD Tank at 0.10% Full.

		Rhinoceros V4.0 SR9					Maxsurf Stability Advanced: V20.00.01.59					Relative Error				
Heel [deg]	Trim [deg]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [%]	Sounding [%]	LCG [%]	VCG [%]	TCG [%]
0.00	0.00	0.13	0.01	17.50	0.00	2.50	0.12	0.01	17.50	0.00	2.50	4.00	0.00	0.00	0.00	0.00
-1.00	0.00	0.13	0.03	17.50	0.01	0.56	0.12	0.03	17.50	0.01	0.56	4.00	0.00	0.00	0.00	0.00
1.00	0.00	0.13	-0.06	17.50	0.01	4.44	0.12	-0.06	17.50	0.01	4.44	4.00	0.00	0.00	0.00	0.00
0.00	-1.00	0.13	-0.32	19.44	0.01	2.50	0.12	-0.32	19.43	0.01	2.50	4.00	0.00	0.05	0.00	0.00
0.00	1.00	0.13	0.29	15.56	0.01	2.50	0.12	0.29	15.57	0.01	2.50	4.00	0.00	-0.06	0.00	0.00

Table C2 SB FWD Tank at 25% Full.

		Rhinoceros V4.0 SR9					Maxsurf Stability Advanced: V20.00.01.59					Relative Error				
Heel [deg]	Trim [deg]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [%]	Sounding [%]	LCG [%]	VCG [%]	TCG [%]
0.00	0.00	31.25	1.25	17.50	0.63	2.50	31.25	1.25	17.50	0.63	2.50	0.00	0.00	0.00	0.00	0.00
-1.00	0.00	31.25	1.29	17.50	0.63	2.47	31.25	1.29	17.50	0.63	2.47	0.00	0.00	0.00	0.00	0.00
1.00	0.00	31.25	1.21	17.50	0.63	2.53	31.25	1.21	17.50	0.63	2.53	0.00	0.00	0.00	0.00	0.00
0.00	-1.00	31.25	0.95	17.53	0.63	2.50	31.25	0.94	17.53	0.63	2.50	0.00	1.05	0.00	0.00	0.00
0.00	1.00	31.25	1.56	17.47	0.63	2.50	31.25	1.56	17.47	0.63	2.50	0.00	0.00	0.00	0.00	0.00

Table C3 SB FWD Tank at 50% Full.

		Rhinoceros V4.0 SR9					Maxsurf Stability Advanced: V20.00.01.59					Relative Error				
Heel [deg]	Trim [deg]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [%]	Sounding [%]	LCG [%]	VCG [%]	TCG [%]
0.00	0.00	62.50	2.50	17.50	1.25	2.50	62.49	2.50	17.50	1.25	2.50	0.02	0.00	0.00	0.00	0.00
-1.00	0.00	62.50	2.54	17.50	1.25	2.49	62.49	2.54	17.50	1.25	2.49	0.02	0.00	0.00	0.00	0.00
1.00	0.00	62.50	2.46	17.50	1.25	2.52	62.49	2.46	17.50	1.25	2.51	0.02	0.00	0.00	0.00	0.40
0.00	-1.00	62.50	2.20	17.52	1.25	2.50	62.49	2.19	17.51	1.25	2.50	0.02	0.45	0.06	0.00	0.00
0.00	1.00	62.50	2.81	17.49	1.25	2.50	62.49	2.81	17.49	1.25	2.50	0.02	0.00	0.00	0.00	0.00

Table C4 SB FWD Tank at 75% Full.

		Rhinoceros V4.0 SR9					Maxsurf Stability Advanced: V20.00.01.59					Relative Error				
Heel [deg]	Trim [deg]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [%]	Sounding [%]	LCG [%]	VCG [%]	TCG [%]
0.00	0.00	93.75	3.75	17.50	1.88	2.50	93.74	3.75	17.50	1.88	2.50	0.01	0.00	0.00	0.00	0.00
-1.00	0.00	93.75	3.79	17.50	1.88	2.49	93.74	3.79	17.50	1.88	2.49	0.01	0.00	0.00	0.00	0.00
1.00	0.00	93.75	3.71	17.50	1.88	2.51	93.74	3.71	17.50	1.88	2.51	0.01	0.00	0.00	0.00	0.00
0.00	-1.00	93.75	3.45	17.51	1.88	2.50	93.74	3.44	17.51	1.88	2.50	0.01	0.29	0.00	0.00	0.00
0.00	1.00	93.75	4.06	17.49	1.88	2.50	93.74	4.06	17.49	1.88	2.50	0.01	0.00	0.00	0.00	0.00

Table C5 SB FWD Tank at 99.9% Full.

		Rhinoceros V4.0 SR9					Maxsurf Stability Advanced: V20.00.01.59					Relative Error				
Heel [deg]	Trim [deg]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [m^3]	Sounding [m]	LCG [m]	VCG [m]	TCG [m]	Volume [%]	Sounding [%]	LCG [%]	VCG [%]	TCG [%]
0.00	0.00	124.88	5.00	17.50	2.50	2.50	124.86	5.00	17.50	2.50	2.50	0.01	0.00	0.00	0.00	0.00
-1.00	0.00	124.88	5.06	17.50	2.50	2.50	124.86	5.06	17.50	2.50	2.50	0.01	0.00	0.00	0.00	0.00
1.00	0.00	124.88	4.97	17.50	2.50	2.50	124.86	4.97	17.50	2.50	2.50	0.01	0.00	0.00	0.00	0.00
0.00	-1.00	124.88	4.71	17.50	2.50	2.50	124.86	4.71	17.50	2.50	2.50	0.01	0.00	0.00	0.00	0.00
0.00	1.00	124.88	5.32	17.50	2.50	2.50	124.86	5.32	17.50	2.50	2.50	0.01	0.00	0.00	0.00	0.00

C.2. Comparison of Rhinoceros 3D V4.0 against Maxsurf Stability: Free-Surface Moment and Free-Surface Area

Table C6 SB FWD Tank at 0.10% Full.

		Rhinoceros V4.0 SR9		Maxsurf Stability Advanced: V20.00.01.59		Relative Error	
Heel [deg]	Trim [deg]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [%]	Free-Surface Area [%]
0.00	0.00	52.08	25.00	52.08	25.00	0.00	0.00
-1.00	0.00	2.02	8.46	2.02	8.46	0.00	0.00
1.00	0.00	2.02	8.46	2.02	8.46	0.00	0.00
0.00	-1.00	17.64	8.46	17.79	8.54	-0.85	-0.95
0.00	1.00	17.64	8.46	17.54	8.42	0.57	0.47

Table C7 SB FWD Tank at 25% Full.

		Rhinoceros V4.0 SR9		Maxsurf Stability Advanced: V20.00.01.59		Relative Error	
Heel [deg]	Trim [deg]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [%]	Free-Surface Area [%]
0.00	0.00	52.08	25.00	52.08	25.00	0.00	0.00
-1.00	0.00	52.08	25.00	52.10	25.00	-0.04	0.00
1.00	0.00	52.08	25.00	52.10	25.00	-0.04	0.00
0.00	-1.00	52.08	25.00	52.09	25.00	-0.02	0.00
0.00	1.00	52.08	25.00	52.09	25.00	-0.02	0.00

Table C8 SB FWD Tank at 50% Full.

		Rhinoceros V4.0 SR9		Maxsurf Stability Advanced: V20.00.01.59		Relative Error	
Heel [deg]	Trim [deg]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [%]	Free-Surface Area [%]
0.00	0.00	52.08	25.00	52.08	25.00	0.00	0.00
-1.00	0.00	52.08	25.00	52.10	25.00	-0.04	0.00
1.00	0.00	52.08	25.00	52.10	25.00	-0.04	0.00
0.00	-1.00	52.08	25.00	52.09	25.00	-0.02	0.00
0.00	1.00	52.08	25.00	52.09	25.00	-0.02	0.00

Table C9 SB FWD Tank at 75% Full.

		Rhinoceros V4.0 SR9		Maxsurf Stability Advanced: V20.00.01.59		Relative Error	
Heel [deg]	Trim [deg]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [%]	Free-Surface Area [%]
0.00	0.00	52.08	25.00	52.08	25.00	0.00	0.00
-1.00	0.00	52.08	25.00	52.10	25.00	-0.04	0.00
1.00	0.00	52.08	25.00	52.10	25.00	-0.04	0.00
0.00	-1.00	52.08	25.00	52.09	25.00	-0.02	0.00
0.00	1.00	52.08	25.00	52.09	25.00	-0.02	0.00

Table C10 SB FWD Tank at 99.9% Full.

		Rhinoceros V4.0 SR9		Maxsurf Stability Advanced: V20.00.01.59		Relative Error	
Heel [deg]	Trim [deg]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [m-tonne]	Free-Surface Area [m^2]	Free-Surface Moment [%]	Free-Surface Area [%]
0.00	0.00	52.08	25.00	52.08	25.00	0.00	0.00
-1.00	0.00	2.02	8.46	2.02	8.46	0.00	0.00
1.00	0.00	2.02	8.46	2.02	8.46	0.00	0.00
0.00	-1.00	17.64	8.46	17.54	8.42	0.57	0.47
0.00	1.00	17.64	8.46	17.79	8.54	-0.85	-0.95

Note that the method of calculating the tank free-surface moment data presented under the Rhinoceros 3D column involved using the tank's free-surface width and length dimensions measured directly from the Rhinoceros 3D solid model and applying the standard formula: Free-Surface = fluid free-surface moment of inertia (m^4) x density of the fluid in the tank (t/m^3). As previously noted, the density of the fluid in the tanks is 1 t/m^3 (fresh water).

C.3. Comparison of Rhinoceros 3D V4.0 against Maxsurf Stability: Volume moments of inertia (I_{xx}, I_{yy} and I_{zz}) and Product moments of inertia (I_{xy}, I_{yz} and I_{xz})

Table C11 SB FWD Tank at 0.10% Full.

		Rhinoceros V4.0 SR9						Maxsurf Stability Advanced: V20.00.01.59						Relative Error					
Heel [deg]	Trim [deg]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [%]	I_{yy} [%]	I_{zz} [%]	I_{xy} [%]	I_{yz} [%]	I_{xz} [%]
0.00	0.00	0.26	0.26	0.52	0.00	0.00	0.00	0.26	0.26	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-1.00	0.00	0.02	0.26	0.28	0.00	0.00	0.00	0.02	0.26	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	0.02	0.26	0.28	0.00	0.00	0.00	0.02	0.26	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	-1.00	0.26	0.02	0.28	0.00	0.00	0.00	0.26	0.02	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.26	0.02	0.28	0.00	0.00	0.00	0.26	0.02	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table C12 SB FWD Tank at 25% Full.

		Rhinoceros V4.0 SR9						Maxsurf Stability Advanced: V20.00.01.59						Relative Error					
Heel [deg]	Trim [deg]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [%]	I_{yy} [%]	I_{zz} [%]	I_{xy} [%]	I_{yz} [%]	I_{xz} [%]
0.00	0.00	69.17	69.17	130.21	0.00	0.00	0.00	69.17	69.36	130.39	0.00	0.00	0.00	0.00	-0.27	-0.14	0.00	0.00	0.00
-1.00	0.00	69.15	69.18	130.18	0.00	0.57	0.00	69.18	69.34	130.36	0.00	0.57	0.00	-0.04	-0.23	-0.14	0.00	0.00	0.00
1.00	0.00	69.15	69.18	130.18	0.00	-0.57	0.00	69.18	69.34	130.36	0.00	-0.57	0.00	-0.04	-0.23	-0.14	0.00	0.00	0.00
0.00	-1.00	69.18	69.15	130.18	0.00	0.00	0.57	69.18	69.34	130.36	0.00	0.00	0.57	0.00	-0.27	-0.14	0.00	0.00	0.00
0.00	1.00	69.18	69.15	130.18	0.00	0.00	-0.57	69.18	69.34	130.36	0.00	0.00	-0.57	0.00	-0.27	-0.14	0.00	0.00	0.00

Table C13 SB FWD Tank at 50% Full.

		Rhinoceros V4.0 SR9						Maxsurf Stability Advanced: V20.00.01.59						Relative Error					
Heel [deg]	Trim [deg]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [%]	I_{yy} [%]	I_{zz} [%]	I_{xy} [%]	I_{yz} [%]	I_{xz} [%]
0.00	0.00	162.76	162.76	260.42	0.00	0.00	0.00	162.74	163.13	260.77	0.00	0.00	0.00	0.01	-0.23	-0.13	0.00	0.00	0.00
-1.00	0.00	162.76	162.77	260.40	0.00	1.14	0.00	162.76	163.13	260.76	0.00	1.14	0.00	0.00	-0.22	-0.14	0.00	0.00	0.00
1.00	0.00	162.76	162.77	260.40	0.00	-1.14	0.00	162.76	163.13	260.76	0.00	-1.14	0.00	0.00	-0.22	-0.14	0.00	0.00	0.00
0.00	-1.00	162.77	162.76	260.41	0.00	0.00	1.14	162.76	163.13	260.76	0.00	0.00	1.14	0.01	-0.23	-0.13	0.00	0.00	0.00
0.00	1.00	162.77	162.76	260.40	0.00	0.00	-1.14	162.76	163.13	260.76	0.00	0.00	-1.14	0.01	-0.23	-0.14	0.00	0.00	0.00

Table C14 SB FWD Tank at 75% Full.

		Rhinoceros V4.0 SR9						Maxsurf Stability Advanced: V20.00.01.59						Relative Error					
Heel [deg]	**Trim [deg]**	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [%]	I_{yy} [%]	I_{zz} [%]	I_{xy} [%]	I_{yz} [%]	I_{xz} [%]
0.00	0.00	305.18	305.18	390.63	0.00	0.00	0.00	305.15	305.72	391.16	0.00	0.00	0.00	0.01	-0.18	-0.14	0.00	0.00	0.00
-1.00	0.00	305.18	305.16	390.63	0.00	1.70	0.00	305.18	305.74	391.15	0.00	1.70	0.00	0.00	-0.19	-0.13	0.00	0.00	0.00
1.00	0.00	305.18	305.16	390.63	0.00	-1.70	0.00	305.18	305.74	391.15	0.00	-1.70	0.00	0.00	-0.19	-0.13	0.00	0.00	0.00
0.00	-1.00	305.17	305.19	390.64	0.00	0.00	1.70	305.18	305.74	391.15	0.00	0.00	1.71	0.00	-0.18	-0.13	0.00	0.00	-0.59
0.00	1.00	305.16	305.18	390.63	0.00	0.00	-1.70	305.18	305.74	391.15	0.00	0.00	-1.71	-0.01	-0.18	-0.13	0.00	0.00	-0.59

Table C15 SB FWD Tank at 99.9% Full.

		Rhinoceros V4.0 SR9						Maxsurf Stability Advanced: V20.00.01.59						Relative Error					
Heel [deg]	**Trim [deg]**	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [m^5]	I_{yy} [m^5]	I_{zz} [m^5]	I_{xy} [m^5]	I_{yz} [m^5]	I_{xz} [m^5]	I_{xx} [%]	I_{yy} [%]	I_{zz} [%]	I_{xy} [%]	I_{yz} [%]	I_{xz} [%]
0.00	0.00	519.79	519.79	520.31	0.00	0.00	0.00	519.74	520.51	521.03	0.00	0.00	0.00	0.01	-0.14	-0.14	0.00	0.00	0.00
-1.00	0.00	519.57	519.78	520.11	0.00	0.60	0.00	519.75	520.28	520.80	0.00	0.60	0.00	-0.03	-0.10	-0.13	0.00	0.00	0.00
1.00	0.00	519.57	519.78	520.11	0.00	-0.60	0.00	519.75	520.28	520.80	0.00	-0.60	0.00	-0.03	-0.10	-0.13	0.00	0.00	0.00
0.00	-1.00	519.78	519.57	520.11	0.00	0.00	0.60	519.75	520.28	520.80	0.00	0.00	0.60	0.01	-0.14	-0.13	0.00	0.00	0.00
0.00	1.00	519.78	519.57	520.11	0.00	0.00	-0.60	519.75	520.28	520.80	0.00	0.00	-0.60	0.01	-0.14	-0.13	0.00	0.00	0.00

Appendix D: Verification Reference Maxsurf Stability Tank Calibration File

D.1. Maxsurf Stability Tank Calibration output file (*.OUT): MARIN barge test case in an upright (zero heel and trim) condition

```
DESIGN DRAFT     (+ ABOVE BL)       2.000  M
DESIGN TRIM      (+ BY STERN)       0.000  M
LENGTH BETWEEN PERPENDICULARS      40.000 METERS

                Approximate Bounding Cube Values:
    ------------------------------------------------------
       Forward X location             40.000  M (+Aft FP)
       After   X location              0.000  M (+Aft FP)
       PORT    Y value on Station     -5.000  M
       STBD    Y value on Station      5.000  M
       Lowest  Z value on Station      0.000  M (+Abv BL)
       Highest Z value on Station      5.000  M (+Abv BL)

                        INPUT COMPARTMENT DESCRIPTIONS
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ID	NAME	SYM	PERM	X1D	X2D	Y1D	Y2D	Z1D	Z2D	ROFF
101	Fwd_PS	0	1.00	0.00	5.00	0.00	-5.00	0.00	5.00	0
102	Fwd_SB	0	1.00	0.00	5.00	5.00	0.00	0.00	5.00	0
103	Aft_PS	0	1.00	35.00	40.00	0.00	-5.00	0.00	5.00	0
104	Aft_SB	0	1.00	35.00	40.00	5.00	0.00	0.00	5.00	0

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1SHIP-

            TANK CAPACITY & FREE SURFACE CALCULATIONS FOR TRIM =    0.00
  101 =   Fwd_PS

TANK: COMP    101     COMPARTMENTS INC. 101

Total compartment capacity      124.99 TONNES @       1.000 M^3/TONNE

Heel=        0.00 Deg                 Fluid Volume Properties
Trim=        0.00 Deg ---------------------------------------------------------
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% FULL	SOUNDING (M)	VOLUME (M^3)	CAPACITY (TONNE)	LCG (M)	VCG (M)	TCG (M)	FS (M-TONNE)	S (M^2)	Ixx (M^5)	Iyy (M^5)	Izz (M^5)	Ixy (M^5)	Iyz (M^5)	Ixz (M^5)
0.00	0.00	0.00	0.00	17.50	0.00	-2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	0.01	0.12	0.12	17.50	0.00	-2.50	52.08	25.00	0.26	0.26	0.52	0.00	0.00	0.00
5.00	0.25	6.25	6.25	17.50	0.13	-2.50	52.08	25.00	13.05	13.09	26.08	0.00	0.00	0.00
10.00	0.50	12.50	12.50	17.50	0.25	-2.50	52.08	25.00	26.30	26.38	52.15	0.00	0.00	0.00
15.00	0.75	18.75	18.75	17.50	0.38	-2.50	52.08	25.00	39.94	40.05	78.23	0.00	0.00	0.00
20.00	1.00	25.00	25.00	17.50	0.50	-2.50	52.08	25.00	54.16	54.31	104.31	0.00	0.00	0.00
25.00	1.25	31.25	31.25	17.50	0.63	-2.50	52.08	25.00	69.17	69.36	130.39	0.00	0.00	0.00
30.00	1.50	37.50	37.50	17.50	0.75	-2.50	52.08	25.00	85.15	85.38	156.46	0.00	0.00	0.00
35.00	1.75	43.75	43.75	17.50	0.88	-2.50	52.08	25.00	102.30	102.57	182.54	0.00	0.00	0.00
40.00	2.00	50.00	50.00	17.50	1.00	-2.50	52.08	25.00	120.82	121.13	208.62	0.00	0.00	0.00
45.00	2.25	56.24	56.24	17.50	1.13	-2.50	52.08	25.00	140.90	141.25	234.70	0.00	0.00	0.00
50.00	2.50	62.49	62.49	17.50	1.25	-2.50	52.08	25.00	162.74	163.13	260.77	0.00	0.00	0.00
55.00	2.75	68.74	68.74	17.50	1.38	-2.50	52.08	25.00	186.54	186.96	286.85	0.00	0.00	0.00
60.00	3.00	74.99	74.99	17.50	1.50	-2.50	52.08	25.00	212.48	212.94	312.93	0.00	0.00	0.00
65.00	3.25	81.24	81.24	17.50	1.63	-2.50	52.08	25.00	240.76	241.26	339.01	0.00	0.00	0.00
70.00	3.50	87.49	87.49	17.50	1.75	-2.50	52.08	25.00	271.59	272.12	365.08	0.00	0.00	0.00
75.00	3.75	93.74	93.74	17.50	1.88	-2.50	52.08	25.00	305.15	305.72	391.16	0.00	0.00	0.00
80.00	4.00	99.99	99.99	17.50	2.00	-2.50	52.08	25.00	341.63	342.25	417.24	0.00	0.00	0.00
85.00	4.25	106.24	106.24	17.50	2.13	-2.50	52.08	25.00	381.24	381.90	443.32	0.00	0.00	0.00
90.00	4.50	112.49	112.49	17.50	2.25	-2.50	52.08	25.00	424.18	424.87	469.39	0.00	0.00	0.00
95.00	4.75	118.74	118.74	17.50	2.38	-2.50	52.08	25.00	470.62	471.35	495.47	0.00	0.00	0.00
99.90	5.00	124.86	124.86	17.50	2.50	-2.50	52.08	25.00	519.74	520.51	521.03	0.00	0.00	0.00
100.00	5.01	124.99	124.99	17.50	2.50	-2.50	0.00	0.00	520.78	521.55	521.55	0.00	0.00	0.00

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1SHIP-
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TANK CAPACITY & FREE SURFACE CALCULATIONS FOR TRIM = 0.00

102 = Fwd_SB

TANK: COMP 102 COMPARTMENTS INC. 102

Total compartment capacity 124.99 TONNES @ 1.000 M^3/TONNE

Heel= 0.00 Deg Fluid Volume Properties

Trim= 0.00 Deg --

% FULL	SOUNDING (M)	VOLUME (M^3)	CAPACITY (TONNE)	LCG (M)	VCG (M)	TCG (M)	FS (M-TONNE)	S (M^2)	Ixx (M^5)	Iyy (M^5)	Izz (M^5)	Ixy (M^5)	Iyz (M^5)	Ixz (M^5)
0.00	0.00	0.00	0.00	17.50	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	0.01	0.12	0.12	17.50	0.00	2.50	52.08	25.00	0.26	0.26	0.52	0.00	0.00	0.00
5.00	0.25	6.25	6.25	17.50	0.13	2.50	52.08	25.00	13.05	13.09	26.08	0.00	0.00	0.00
10.00	0.50	12.50	12.50	17.50	0.25	2.50	52.08	25.00	26.30	26.38	52.15	0.00	0.00	0.00
15.00	0.75	18.75	18.75	17.50	0.38	2.50	52.08	25.00	39.94	40.05	78.23	0.00	0.00	0.00
20.00	1.00	25.00	25.00	17.50	0.50	2.50	52.08	25.00	54.16	54.31	104.31	0.00	0.00	0.00
25.00	1.25	31.25	31.25	17.50	0.63	2.50	52.08	25.00	69.17	69.36	130.39	0.00	0.00	0.00
30.00	1.50	37.50	37.50	17.50	0.75	2.50	52.08	25.00	85.15	85.38	156.46	0.00	0.00	0.00
35.00	1.75	43.75	43.75	17.50	0.88	2.50	52.08	25.00	102.30	102.57	182.54	0.00	0.00	0.00
40.00	2.00	50.00	50.00	17.50	1.00	2.50	52.08	25.00	120.82	121.13	208.62	0.00	0.00	0.00
45.00	2.25	56.24	56.24	17.50	1.13	2.50	52.08	25.00	140.90	141.25	234.70	0.00	0.00	0.00
50.00	2.50	62.49	62.49	17.50	1.25	2.50	52.08	25.00	162.74	163.13	260.77	0.00	0.00	0.00
55.00	2.75	68.74	68.74	17.50	1.38	2.50	52.08	25.00	186.54	186.96	286.85	0.00	0.00	0.00
60.00	3.00	74.99	74.99	17.50	1.50	2.50	52.08	25.00	212.48	212.94	312.93	0.00	0.00	0.00
65.00	3.25	81.24	81.24	17.50	1.63	2.50	52.08	25.00	240.76	241.26	339.01	0.00	0.00	0.00
70.00	3.50	87.49	87.49	17.50	1.75	2.50	52.08	25.00	271.59	272.12	365.08	0.00	0.00	0.00
75.00	3.75	93.74	93.74	17.50	1.88	2.50	52.08	25.00	305.15	305.72	391.16	0.00	0.00	0.00
80.00	4.00	99.99	99.99	17.50	2.00	2.50	52.08	25.00	341.63	342.25	417.24	0.00	0.00	0.00
85.00	4.25	106.24	106.24	17.50	2.13	2.50	52.08	25.00	381.24	381.90	443.32	0.00	0.00	0.00
90.00	4.50	112.49	112.49	17.50	2.25	2.50	52.08	25.00	424.18	424.87	469.39	0.00	0.00	0.00
95.00	4.75	118.74	118.74	17.50	2.38	2.50	52.08	25.00	470.62	471.35	495.47	0.00	0.00	0.00
99.90	5.00	124.86	124.86	17.50	2.50	2.50	52.08	25.00	519.74	520.51	521.03	0.00	0.00	0.00
100.00	5.01	124.99	124.99	17.50	2.50	2.50	0.00	0.00	520.78	521.55	521.55	0.00	0.00	0.00

1SHIP-

TANK CAPACITY & FREE SURFACE CALCULATIONS FOR TRIM = 0.00

103 = Aft_PS

TANK: COMP 103 COMPARTMENTS INC. 103

Total compartment capacity 124.99 TONNES @ 1.000 M^3/TONNE

Heel= 0.00 Deg Fluid Volume Properties

Trim= 0.00 Deg --

% FULL	SOUNDING (M)	VOLUME (M^3)	CAPACITY (TONNE)	LCG (M)	VCG (M)	TCG (M)	FS (M-TONNE)	S (M^2)	Ixx (M^5)	Iyy (M^5)	Izz (M^5)	Ixy (M^5)	Iyz (M^5)	Ixz (M^5)
0.00	0.00	0.00	0.00	-17.50	0.00	-2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	0.01	0.12	0.12	-17.50	0.00	-2.50	52.08	25.00	0.26	0.26	0.52	0.00	0.00	0.00
5.00	0.25	6.25	6.25	-17.50	0.13	-2.50	52.08	25.00	13.05	13.09	26.08	0.00	0.00	0.00
10.00	0.50	12.50	12.50	-17.50	0.25	-2.50	52.08	25.00	26.30	26.38	52.15	0.00	0.00	0.00
15.00	0.75	18.75	18.75	-17.50	0.38	-2.50	52.08	25.00	39.94	40.05	78.23	0.00	0.00	0.00
20.00	1.00	25.00	25.00	-17.50	0.50	-2.50	52.08	25.00	54.16	54.31	104.31	0.00	0.00	0.00
25.00	1.25	31.25	31.25	-17.50	0.63	-2.50	52.08	25.00	69.17	69.36	130.39	0.00	0.00	0.00
30.00	1.50	37.50	37.50	-17.50	0.75	-2.50	52.08	25.00	85.15	85.38	156.46	0.00	0.00	0.00
35.00	1.75	43.75	43.75	-17.50	0.88	-2.50	52.08	25.00	102.30	102.57	182.54	0.00	0.00	0.00
40.00	2.00	50.00	50.00	-17.50	1.00	-2.50	52.08	25.00	120.82	121.13	208.62	0.00	0.00	0.00
45.00	2.25	56.24	56.24	-17.50	1.13	-2.50	52.08	25.00	140.90	141.25	234.70	0.00	0.00	0.00
50.00	2.50	62.49	62.49	-17.50	1.25	-2.50	52.08	25.00	162.74	163.13	260.77	0.00	0.00	0.00
55.00	2.75	68.74	68.74	-17.50	1.38	-2.50	52.08	25.00	186.54	186.96	286.85	0.00	0.00	0.00
60.00	3.00	74.99	74.99	-17.50	1.50	-2.50	52.08	25.00	212.48	212.94	312.93	0.00	0.00	0.00
65.00	3.25	81.24	81.24	-17.50	1.63	-2.50	52.08	25.00	240.76	241.26	339.01	0.00	0.00	0.00
70.00	3.50	87.49	87.49	-17.50	1.75	-2.50	52.08	25.00	271.59	272.12	365.08	0.00	0.00	0.00
75.00	3.75	93.74	93.74	-17.50	1.88	-2.50	52.08	25.00	305.15	305.72	391.16	0.00	0.00	0.00
80.00	4.00	99.99	99.99	-17.50	2.00	-2.50	52.08	25.00	341.63	342.25	417.24	0.00	0.00	0.00
85.00	4.25	106.24	106.24	-17.50	2.13	-2.50	52.08	25.00	381.24	381.90	443.32	0.00	0.00	0.00
90.00	4.50	112.49	112.49	-17.50	2.25	-2.50	52.08	25.00	424.18	424.87	469.39	0.00	0.00	0.00
95.00	4.75	118.74	118.74	-17.50	2.38	-2.50	52.08	25.00	470.62	471.35	495.47	0.00	0.00	0.00
99.90	5.00	124.86	124.86	-17.50	2.50	-2.50	52.08	25.00	519.74	520.51	521.03	0.00	0.00	0.00
100.00	5.01	124.99	124.99	-17.50	2.50	-2.50	0.00	0.00	520.78	521.55	521.55	0.00	0.00	0.00

1SHIP-

TANK CAPACITY & FREE SURFACE CALCULATIONS FOR TRIM = 0.00
104 = Aft_SB

TANK: COMP 104 COMPARTMENTS INC. 104

Total compartment capacity 124.99 TONNES @ 1.000 M^3/TONNE

Heel= 0.00 Deg
Trim= 0.00 Deg

Fluid Volume Properties

% FULL	SOUNDING (M)	VOLUME (M^3)	CAPACITY (TONNE)	LCG (M)	VCG (M)	TCG (M)	FS (M-TONNE)	S (M^2)	Ixx (M^5)	Iyy (M^5)	Izz (M^5)	Ixy (M^5)	Iyz (M^5)	Ixz (M^5)
0.00	0.00	0.00	0.00	-17.50	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	0.01	0.12	0.12	-17.50	0.00	2.50	52.08	25.00	0.26	0.26	0.52	0.00	0.00	0.00
5.00	0.25	6.25	6.25	-17.50	0.13	2.50	52.08	25.00	13.05	13.09	26.08	0.00	0.00	0.00
10.00	0.50	12.50	12.50	-17.50	0.25	2.50	52.08	25.00	26.30	26.38	52.15	0.00	0.00	0.00
15.00	0.75	18.75	18.75	-17.50	0.38	2.50	52.08	25.00	39.94	40.05	78.23	0.00	0.00	0.00
20.00	1.00	25.00	25.00	-17.50	0.50	2.50	52.08	25.00	54.16	54.31	104.31	0.00	0.00	0.00
25.00	1.25	31.25	31.25	-17.50	0.63	2.50	52.08	25.00	69.17	69.36	130.39	0.00	0.00	0.00
30.00	1.50	37.50	37.50	-17.50	0.75	2.50	52.08	25.00	85.15	85.38	156.46	0.00	0.00	0.00
35.00	1.75	43.75	43.75	-17.50	0.88	2.50	52.08	25.00	102.30	102.57	182.54	0.00	0.00	0.00
40.00	2.00	50.00	50.00	-17.50	1.00	2.50	52.08	25.00	120.82	121.13	208.62	0.00	0.00	0.00
45.00	2.25	56.24	56.24	-17.50	1.13	2.50	52.08	25.00	140.90	141.25	234.70	0.00	0.00	0.00
50.00	2.50	62.49	62.49	-17.50	1.25	2.50	52.08	25.00	162.74	163.13	260.77	0.00	0.00	0.00
55.00	2.75	68.74	68.74	-17.50	1.38	2.50	52.08	25.00	186.54	186.96	286.85	0.00	0.00	0.00
60.00	3.00	74.99	74.99	-17.50	1.50	2.50	52.08	25.00	212.48	212.94	312.93	0.00	0.00	0.00
65.00	3.25	81.24	81.24	-17.50	1.63	2.50	52.08	25.00	240.76	241.26	339.01	0.00	0.00	0.00
70.00	3.50	87.49	87.49	-17.50	1.75	2.50	52.08	25.00	271.59	272.12	365.08	0.00	0.00	0.00
75.00	3.75	93.74	93.74	-17.50	1.88	2.50	52.08	25.00	305.15	305.72	391.16	0.00	0.00	0.00
80.00	4.00	99.99	99.99	-17.50	2.00	2.50	52.08	25.00	341.63	342.25	417.24	0.00	0.00	0.00
85.00	4.25	106.24	106.24	-17.50	2.13	2.50	52.08	25.00	381.24	381.90	443.32	0.00	0.00	0.00
90.00	4.50	112.49	112.49	-17.50	2.25	2.50	52.08	25.00	424.18	424.87	469.39	0.00	0.00	0.00
95.00	4.75	118.74	118.74	-17.50	2.38	2.50	52.08	25.00	470.62	471.35	495.47	0.00	0.00	0.00
99.90	5.00	124.86	124.86	-17.50	2.50	2.50	52.08	25.00	519.74	520.51	521.03	0.00	0.00	0.00
100.00	5.01	124.99	124.99	-17.50	2.50	2.50	0.00	0.00	520.78	521.55	521.55	0.00	0.00	0.00

1SHIP-

Appendix E: Tank Table Processor Plot of Maxsurf Stability Generated Free-Surface Area Data

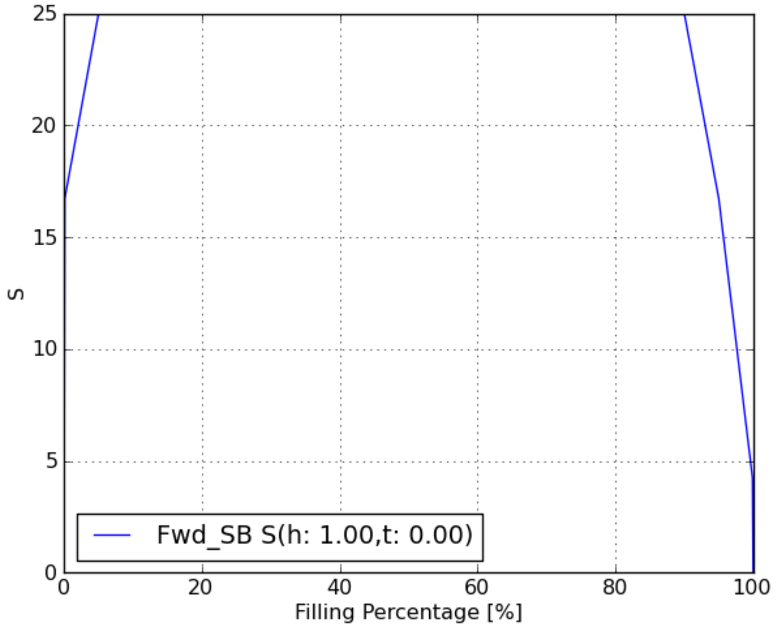


Figure E1 Tank Table Processor plot of SB Fwd tank free-surface area (S) as a function of filling percentage for a 1 degree heel to starboard condition.

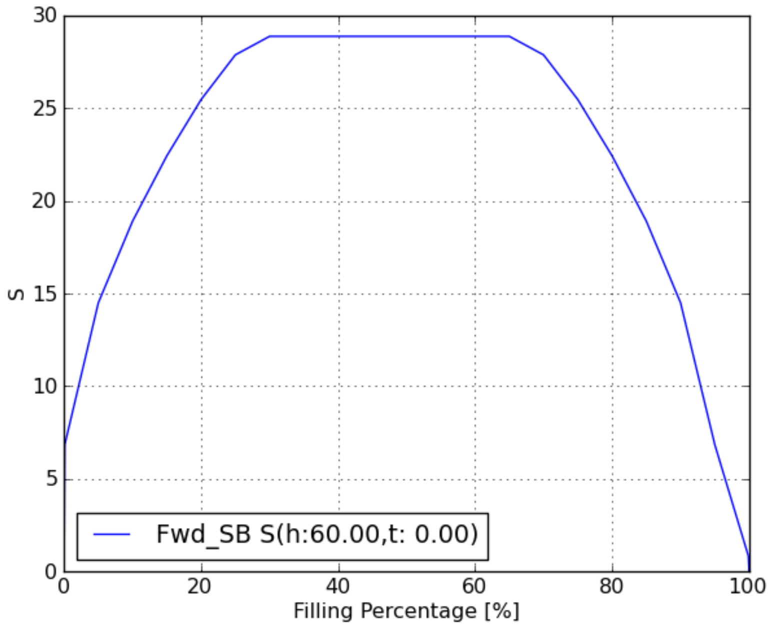


Figure E2 Tank Table Processor plot of SB Fwd tank free-surface area (S) as a function of filling percentage for a 60 degree heel to starboard condition.

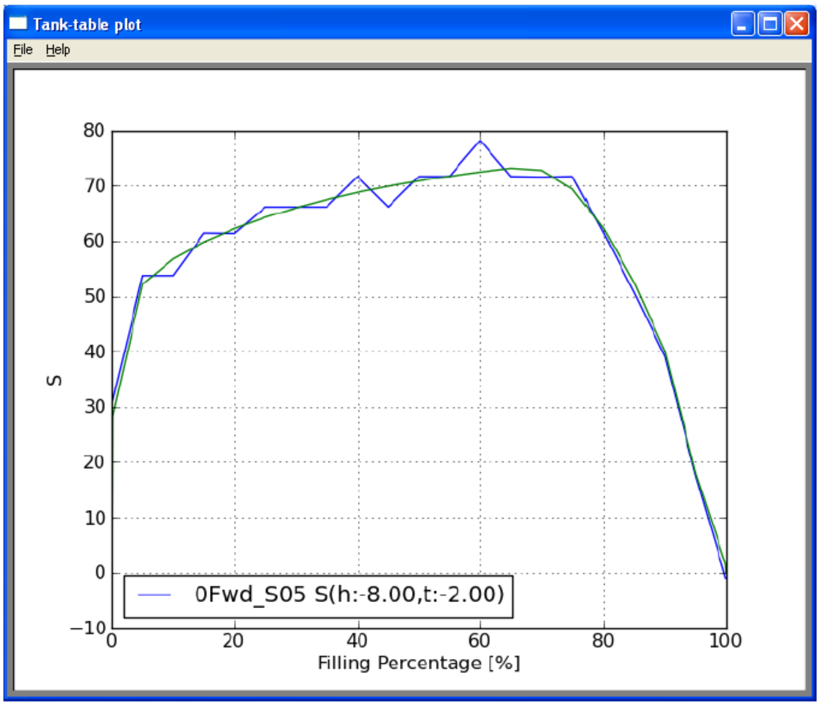


Figure E3 Tank Table Processor plot of tank free-surface area (S) as a function of filling percentage for a combined 8 degree heel to port and 2 degree trim by the bow condition. Plot indicates the undesirable and unacceptable lack of smoothness in the tank table data (shown as the blue line) (Ypma [3]).

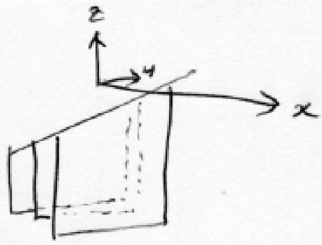
Appendix F: Maxsurf Stability Calculation Method: Second Moments of Inertia

The following hand-written transcript was provided by the developers of Maxsurf Stability (Formation Design Systems) to DSTO on request. The transcript details the method programmed in Maxsurf Stability to calculate the tank second moments of inertia.

TANK INERTIAS

$$I_{xx} = \int_V (y^2 + z^2)\, dV$$

$$= \underbrace{\int_V y^2\, dV}_{\text{section } I_{zz}} + \underbrace{\int z^2\, dV}_{\text{section } I_{yy}}$$



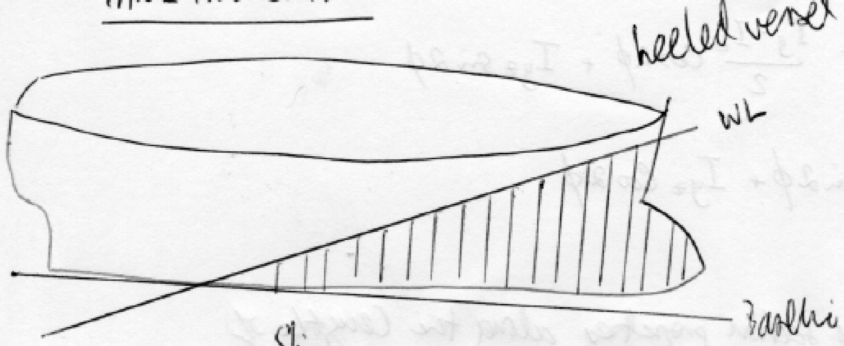
have lots of 2D sections in x=const plane that need to integrate along length to get volumetric properties.

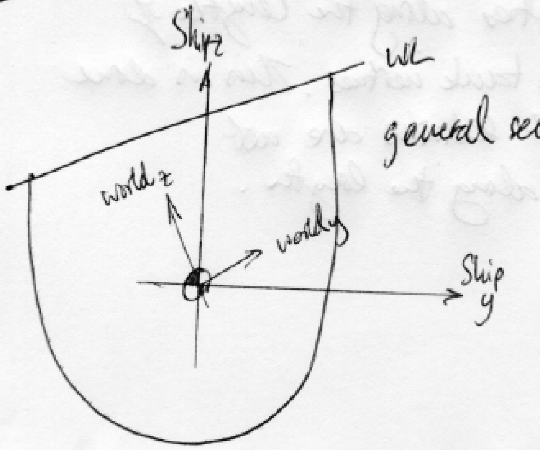
I_{yy} (and similarly I_{zz})

$$I_{yy} = \int_V (x^2 + z^2)\, dV$$

$$= \underbrace{\int_V x^2\, dV}_{\text{section area} \cdot x^2} + \underbrace{\int_V z^2\, dV}_{\text{section } I_{yy}}$$

TANK INTERTIAS





see en.wikipedia.org/wiki/Second_moment_of_area

1/ Calculate centroid of tank in ~~on~~ world coords.

2/ Calculate planar properties of each section in the tank – for the heeled sections about the tank centroid. Polygon has n points assumed closed between point n to point 1

$$I_{yy} = \frac{1}{12}\sum_i \left\{ \left(z_i^2 + z_i z_{i+1} + z_{i+1}^2 \right) a_i \right\}$$

$$I_{zz} = \frac{1}{12}\sum_i \left\{ \left(y_i^2 + y_i y_{i+1} + y_{i+1}^2 \right) a_i \right\}$$

These are in world coords ie parallel and normal to water plane.

$$I_{yz} = \frac{1}{24}\sum_i \left\{ \left(y_i z_{i+1} + 2 y_i z_i + 2 y_{i+1} z_{i+1} + y_{i+1} z_i \right) a_i \right\}$$

$$a_i = y_i z_{i+1} - y_{i+1} z_i$$

3/ Rotate inertias and centroid to get in ship coordinate system

$$I_y' = \frac{I_y + I_z}{2} + \frac{I_y - I_z}{2}\cos 2\phi - I_{yz}\sin 2\phi$$

$$I_z' = \frac{I_y + I_z}{2} - \frac{I_y - I_z}{2}\cos 2\phi + I_{yz}\sin 2\phi$$

$$I_{yz}' = \frac{I_y - I_z}{2}\sin 2\phi + I_{yz}\cos 2\phi$$

4/ Integrate the section properties along the length of the tank to get the total tank inertias. This is done using trapezoidal rule since sections are not necessarily evenly spaced along the length.

if there are nS sections:

for $s = 2$ to nS

$s_0 = s-1$; $s_1 = s$.

x_0 = x position of s_0 from Tank LCG ; similarly for x_1

$\delta I_{xx_0} = \sec I_{yy_0} + \sec I_{zz}$ (similar for δI_{xx_1} etc.)

$\delta I_{yy_0} = \sec I_{yy_0} + \sec Area_0 . x_0^2$

$\delta I_{zz_0} = \sec I_{zz_0} + \sec Area_0 . x_0^2$

$\delta I_{xy_0} = \sec Centroid\, y_0 + \sec Area_0 . x_0$

$\delta I_{yz_0} = \sec I_{yz_0}$

$\delta I_{xz_0} = \sec Centroid\, z_0 + \sec Area_0 . x_0$

$$\underbrace{I_{xx} \mathrel{+}= \frac{x_1 - x_0}{2}\left(\delta I_{xx_0} + \delta I_{xx_1}\right)}_{\text{ie sum over } s = 2 \text{ to } nS.}$$ etc for other inertias.

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Maxsurf Stability, Tank Table, Damage Stability, FREDYN

19. ABSTRACT

This report presents the objectives, methodology and outcomes of the verification and validation analyses of the Maxsurf Stability tank table generator software application. The fundamental objective of the analyses is to provide objective quantitative evidence that the Maxsurf Stability software can be used to generate platform tank calibration data in a format and to a standard that meets, or exceeds, the requirements imposed by the Maritime Institute of the Netherlands (MARIN) and the Cooperative Research Navies (CRNAV) ship stability working group. The results of the analyses show that the Maxsurf Stability software program (Version 20.00.00.59) generates tank calibration data and a tank table output file that meets the aforementioned requirements.